The Importance and Feasibility of Irradiated Low Nitrite Meat Products

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Cured meats represent a large portion of the total meat consumed in the US and the world over. Sales of cured meats in the US amount to over 13 billion, of which bacon alone accounts for $2.7 billion of that sum (USDA, 1979). Over 70% of the pork and 30% of the beef are processed as various cured meat products, the curing agents being nitrite and nitrate.

The main curing compound, sodium nitrite, is added directly to meats. Sodium nitrate can be converted to nitrite during the processing of some cured meats, e.g., fermented sausages. Addition of nitrite is regulated by the USDA Food Safety and Quality Service (FSQS). The latest regulations allow 156 parts per million (ppm) to be added to ham, corned beef, and various pickle-cured products, and 120 ppm to bacon in combination with 550 ppm of sodium ascorbate or sodium isoascorbate (erythorbate).

During the past decade, the use of nitrite and nitrate in curing meat has become very controversial. Nitrite that remains in meats after curing can react with amines, the decomposition products of meat proteins, forming nitrosamines. which are carcinogenic to laboratory animals. In bacon, the situation is more serious, because the nitrosamine, nitrosopyrrolidine (NPYR), is formed during bacon frying. The amount NPYR formed has been shown to be related to the residual nitrite present in raw bacon after curing. It has been further demonstrated on experimental animals that nitrosamines can be formed from residual nitrite and amines derived from meat and other foods in the stomach during consumption. In addition, Newberne (1978) published a report on his 5-year study for the FDA on the effects of nitrites in the diet. The results of this study indicate that nitrite itself could be a carcinogen. The regulatory agencies, USDA-FSQS, have initiated regulatory actions restricting the use of nitrite and nitrate in cured meats and, subject to the outcome of confirmatory studies, may eventually ban their use in cured meats if proper alternatives for nitrite become available.

On 30 March this year, the Justice Department declared that nitrite has to be banned if the results of this Newberne-MIT studies indicate the carcinogenicity of nitrite. On the same day, the USDA-HEW requested the Congress to delay legislation banning nitrite until at least 1 May 1980 - longer in certain cases, if no substitute has been found (Califano, 1979).

Nitrite is used in cured meats chiefly to protect consumers against botulism, a deadly poison resulting from the toxin produced by the bacterium <u>Clostridium botulinum</u>. The added nitrite contributes also to the formation of the desirable color and flavor of the products.

The ban of nitrite will greatly affect the livestock producers, meat industry, food distribution chains, and the consumers. Although nitrite-free pork products could be sold, a ban on the sale of cured meat products would increase the cost of pork, beef, and poultry, since much less pork would be produced. Storage and distribution facilities for handling uncured pork products and other uncured meats would have to be increased and the refrigeration temperature more strictly controlled. The result would be an increased energy cost.

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Other consequences are that consumers will have to change their eating habits and many ethnic meats will disappear from the market. A recent report by USDA (1979) showed that the ban of nitrite in bacon alone could affect the farm income and the consumer price index.

A possible alternative is irradiation, a very effective substitute for nitrite in cured meats. Irradiation will solve all or most of the problems mentioned. It destroys C. botulinum in cured meats, thus eliminating the need for nitrite to control growth and toxin formation by this lethal bacterium.

This paper reports research conducted at the US Army Natick Research and Development Command (NARADCOM) on reduction or elimination of nitrite in ham, corned beef, conventional bacon, and pre-fried bacon preserved by irradiation. Preliminary research results on irradiated frankfurters with reduced nitrite and without nitrite are also given.

EXPERIMENTAL EFFORTS

Processing of cured meats (used in this study) prior to irradiation followed essentially common commercial practice. Details for product preparation, packaging, irradiation and post-irradiation storage and evaluation are given for ham by Howker et al. (1979) and Wierbicki et al. (1973, 1974, 1976); for corned beef, by Shults et al. (1977, 1979); for conventional bacon, by Wierbicki et al. (1974, 1979); and for pre-fried bacon, by Wierbicki et al. (1974) and Heiligman et al. (1979).

Vacuum-packed, hermetically sealed foods were irradiated with gamma rays from the cobalt-60 source or 10 MeV electrons from the linear electron accelerator (Linac) at NARADCOM. For shelf-stable products 12D sterilizing doses, as summarized in Table 1 (in kilograys (kGy) of the absorbed ionizing radiation by the foods (10 kGy equal 1.0 megarad (Mrad)) were used (Anellis et al. (1976). The 12D doses determined by the 'extreme value' method were: for ham, 31.4 kGy at -30 ± 10C; for corned beef, 26.9 kGy at -30 ± 10C; for conventional bacon and pre-fried bacon, 23 kGy at 5 ± 5C and 30 kGy at -30 ± 10C. Before taste testing, all irradiated samples were tested for safety against C. botulinum toxin using a proven microbiological technique. Since irradiation was applied after the foods were vacuum packaged, the irradiation processing represents a 100% aseptic system for packaged foods. During our 25 years experience, there has not been a single case of the positive detection of C. botulinum toxin in the foods processed with sterilizing doses of ionizing radiation.

Sensory evaluation of the products was conducted as follows: (a) a technological panel of 8 to 12 members was used to evaluate color, odor, flavor, and texture, employing the 9-point descriptive scale (9 = excellent, 5 = fair, 1 = extremely poor), and (b) a NARADCOM volunteer, consumer panel was used for reference, using the 9-point hedonic scale for food preferences by Peryam and Pilgrim (1957) (9= like extremely, 5 = neither like nor dislike, and 1 = dislike extremely). The ratings above 5 as determined by both panels, are indicative of products of good quality that can be expected to gain acceptance by a broad range of consumers, both civilian and military.

Nitrosamine determinations were conducted on the experimental samples by the USDA Laboratory, Eastern Regional Research Center in Philadelphia, PA, using the FDA approved technique of gas chromatographic (GC) separation, thermal electron analyzer (TEA) detection, and mass spectrometric (MS) confirmation of the positive GC-TEA findings for the nitrosamines. In ham and corned beef, the determinations were made for six nitrosamines; nitrosodimethylamine (NDMA), nitrosomethylethylamine (NMEA), nitrosodiethylamine (NDEA), nitrosomorpholine (NMOR), nitrosopyrrolidine (NPYR), and nitrosopiperidine (NPIP). In bacon, both conventional and pre-fried, the analyses were conducted only for NDMA and NPYR, since these are the only two nitrosamines detected in bacon.

Possible reductions and elimination of nitrite in irradiated bacon, ham, corned beef, and frankfurters are summarized in Table 2.

1. Ham

The present nitrite addition to ham, allowed by USDA, is 156 ppm and no added nitrate.

In our previous research (Wierbicki et al. 1973, 1974, 1976) the lowest level of added nitrite in irradiated ham was 25 ppm supplemented with 100 ppm nitrate for prevention of fading of cured meat color after irradiation. Over 60,000 kg of ham were procured from industry at these nitrite and nitrate levels and no uncured spots in the product were detected.

One objective of this last series of experiments was to reduce the amount of added nitrate to below 100 ppm when used in combination with 25 ppm nitrite. Another objective was to eliminate nitrite entirely.

Results of the latest experiments indicate that a good quality, shelf-stable smoked ham, preserved by irradiation, can be produced by adding only 25 ppm nitrate in combination with 25 ppm nitrite, along with common curing ingredients, 2.4% salt, 0.3% TPP and 550 ppm ascorbate (Table 3).

Elimination of nitrate entirely requires increasing the added nitrite from 25 to 75 ppm. The resulting product, after irradiation, has less stable color than by using the combination of 25 ppm nitrite and 25 ppm nitrate (Table 4). Consumer acceptance of the ham with added 25 ppm nitrite in combination with 25 ppm nitrate is high, as shown by the preference ratings in Table 5.

Nitrosamines were not detected in any irradiated and non-irradiated ham samples cured with these low additions of nitrite and nitrate, neither shortly after processing nor after storage at 21C for 2 years.

An attempt was made to produce ham without adding nitrite at all. The resulting product was of excellent texture and was shelf stable after irradiation. Unfortunately, the typical color and flavor of ham were lacking. Flavor can be improved by adding ham flavoring compounds, spices and more smoke; however, more research in the field is needed. If the nitrite ban is imposed, it is evident that a shelf-stable ham-like product, preserved by irradiation and made safe from botulism can be produced. However, consumers will have to accept a different color and flavor from that of the product to which they are accustomed.

2. Corned Beef

In corned beef the nitrite addition can be reduced from 156 ppm to 50 ppm. An acceptable product was produced by further reduction of added nitrite to 25 ppm (Shults et al. 1977, Table 6). However, during repeated production of the item in our laboratory uncured spots frequently occurred in the 25 ppm nitrite product. Therefore, 50 ppm added nitrite is recommended for irradiated corned beef (Table 2). The meat industry, with its more sophisticated injecto-pumping equipment, might be able to produce corned beef without uncured spots by using only 25 ppm nitrite addition. Irradiated corned beef is an excellent product, receiving constantly high preference ratings (Table 6). Because of its high quality, shelf-stability, safety from botulism, and dry-pack, it was used in the Apollo-Soyuz space flight in July 1975 (along with irradiated ham, beef steaks, and turkey slices). It was highly praised by the astronauts and cosmonauts. Irradiated corned beef (as well as irradiated beef steaks and turkey slices) have been selected by NASA for future space flight feeding. It should be mentioned that none of the six nitrosamines was detected in the irradiated corned beef samples. An acceptable irradiated corned beef has also been produced without addition of nitrite (Shults et al. 1979). The color of the product, however, was pinkish-brown, instead of the typical corned beef pink. This product is known in the East as New England corned beef and as such should be acceptable to most consumers in the region. The flavor of the product can be improved by adding commercially available corned beef flavor compounds. Further research is needed, however, in this intricate subject, flavor.

3. Frankfurters

Research is in progress to develop irradiated frankfurters, the widely-used comminuted, emulsion-type meat product, under a research contract with Texas A&M University. Results obtained so far indicate that the addition of nitrite in irradiated frankfurters can be reduced to a 50 ppm level (Table 2). Acceptable irradiated frankfurters can also be produced without nitrite addition, but the resulting product is rated inferior in flavor in comparison with nitrite-processed frankfurters. This can be remedied, fortunately, by modifying the spice and cure formula and including flavor enhancing compounds. Research is active in this area, and includes work to produce irradiated, shelf-stable chicken frankfurters without nitrite addition.

4. Bacon

A. Irradiation sterilized (radappertized) bacon

This product, hermetically vacuum-packed in metal cans or flexible pouches, can be stored and distributed without refrigeration. The objectives of this investigation were:

To produce shelf-stable, nitrosamine-free bacon, preserved by sterilizing doses of ionizing radiation, processed with the smallest amount of added nitrite needed to achieve the characteristic color and flavor of the bacon.

To produce shelf-stable bacon of acceptable quality without addition of nitrite.

The use of nitrite in commercial bacon at the present time is 120 ppm in combination with 550 ppm ascorbate. Reduction or elimination of nitrite in bacon is of particular importance because the residual nitrite remaining in bacon forms nitrosopyrrolidine (NPYR) during the frying of the bacon.

1) Conventional (raw) bacon

A series of experiments was conducted using different levels of added nitrite (from 0 to 120 ppm) and nitrate (from 0 to 500 ppm) to bacon bellies during curing; the need for using sugar (sucrose), sodium tripolyphosphate (TPP), and ascorbate was also investigated. The bacon was processed, sliced, vacuum-packed in commercial transparent films in 1 lb units and then shipped in a refrigerated car to NARADCOM for further processing. Before irradiation, the product was repacked into metal cans or flexible pouches, vacuum sealed, and irradiated with sterilizing doses of ionizing radiation, either with 23 kGy at 5C or with 30 kGy at -30 $\pm$ 10C. Table 7 presents the composition of five cures used in the last experiment. The addition of sucrose (0.75%) and TPP (0.3%) are at the levels normally used by industry. Sucrose is needed for browning the product during frying, which is important for the product appearance, particularly for nitrite-free bacon. It also contributes to the taste of the product. The use of TPP is useful in combination with ascorbate or isoascorbate to prevent rancidity development in the product when the containers are opened and the product held in a refrigerator prior to consumption. The salt (NaCl) concentration is slightly lower than that in most commercial bacon, which contains from 2.0 to 2.5% salt. A combination of nitrite and nitrate (Table 7, lot V) was used to obtain information on whether or not this combination will benefit color stability (as found in irradiated ham). Since the combination was shown not to be beneficial, nitrate addition in bacon can be said to be not needed.

The overall evaluation (Wierbicki et al. 1979) showed that the added nitrite can be reduced from the present level of 120 ppm down to 20 ppm with the resulting product retaining all the sensory quality of bacon known to the consumer. A good quality bacon, which received high acceptance by consumer panels at this laboratory, was also produced by eliminating nitrite entirely; however, it had a slightly different flavor and color after frying as judged by meat experts. These data are given in Table 8 for color, odor, flavor and texture, and in Table 9 for consumer preference with regard to the irradiated bacon produced using the cure formulations given in Table 7.

No nitrosamines (NDMA and MPYR) were detected in the bacon made without nitrite. In the product cured with 20 to 40 ppm added nitrite, no NDMA was detected, however, the NPYR content was very low and varied from N.D. (none detected) to 2 ppb (parts per billion), which is below the USDA target level of 5 ppm maximum.

Irradiation destroys residual nitrite in cured bacon with added nitrite, thus decreasing the probability for NPYR formation during frying of bacon; this is shown in Table 10. The data given in Table 10 have been confirmed in a joint study with the USDA Laboratory in Philadelphia in which residual nitrite and the nitrosamines (NDMA and NPYR) were determined in irradiated and nonirradiated bacon, made from paired bacon bellies from the same hogs, further subdivided into the three main sections regarding the lean-fat distribution (brisket, center, flank). Comparison was made between the paired bacon bellies (irradiated vs nonirradiated) cured with 120 vs 20 and 0 ppm added nitrite. In all irradiated bacon samples, including those cured with 120 ppm nitrite, no residual nitrite was detected. There was no NDMA in 0 and 20 ppm bacon; NPYR in irradiated 0 and 20 ppm bacon was in the range as given in Table 10 (from N.D. to 1 ppb). In the bacon cured with 120 ppm nitrite, the amounts of NDMA and NPYR in the irradiated samples were on the average only one-third of the amounts detected in nonirradiated paired bacon samples- unpublished data).

2) Pre-fried bacon

Pre-fried (precooked) bacon offers several advantages, particularly as a military subsistence item, since it can be stored without refrigeration and is reduced in weight by 60% (1 lb pre-fried bacon = 2.5 lbs raw bacon) (Anon. 1977). However, nonirradiated pre-fried bacon must be carefully processed and controlled, because it is not sterile and depends on low water activity and moisture-to-salt ratio for its stability. Since bacon is a very heterogeneous product with respect to lean-fat composition, it is difficult to control its production under industrial conditions to assure the product stability at ambient temperatures. High salt addition is usually used for this product which results in consumers' complaints because of the salty taste of the product. Pre-fried bacon is hand packed, which causes bacterial contamination and can result in bacterial spoilage of the product. There are cases known to the military procurement when pre-fried bacon contained above 10^5 aerobic plate counts per gram in 24% representative samples analyzed. _Staphylococcus aureus_ contamination (which leads to enterotoxin, producing food poisoning symptoms) was as high in some samples as 1.7×10^5/g (Powers et al. 1978). This caused rejection of the bacon production for military procurement, when detected early (Powers et al. 1978) or the recall of the product from the military subsistence. Irradiating pre-fried bacon is probably the most useful usage of this preservation process to the military. It makes it possible to use bacon of lower salt content, does not require very rigid control of moisture-to-salt ratio or water activity, and, since irradiation is done after packaging of the product, assures the destruction of the bacteria introduced during hand packing of the product. By using sterilizing doses of irradition (which is recommended), the resulting product can be stored without refrigeration for years.

Four experiments with irradiated pre-fried bacon have been conducted so far. Representative data from the last experiment are presented here. The raw bacon after processing with the cures listed in Table 7 was pre-fried in 205C preheated oven until reduction in weight-to-raw of 60% was achieved. The resulting product was then vacuum packed in metal containers or flexible pouches and irradiated with sterilizing does of cobalt-60 gamma rays of 23 kGy at 5C or 30 kGy at -30 + 10C.

The product received high quality scores for color, odor, flavor, and texture (Table 11) and for preference by a consumer panel (Table 12). The data shown in these tables confirmed the results obtained during the previous three experiments on pre-fried irradiated bacon. In addition, irradiation makes it possible to reduce added nitrite from 120 to 20 ppm or to eliminate nitrite entirely and still have a safe and acceptable product, as shown by the quality characteristics in Tables 11 and 12. Equally acceptable pre-fried bacon without nitrite or with only 20 ppm added nitrite was obtained by irradiating in the frozen state (-30C) or at refrigerated (5C) temperature (Heiligman et al. 1979). The product produced without nitrite or with only 20 ppm added nitrite was free from residual nitrite and from nitrosodimethylamine (NDMA).

Nitrosopyrrolidine (NPYR) was not detected in the bacon cured without nitrite. The samples cured with 20 ppm nitrite contained no detectable NPYR when the FDA multidetection procedure was used (minimum detectability of the method was 5 ppb) (Wierbicki et al. 1976) or only 1 ppb when the TEA detector (minimum detectability 1 ppb) was used (Table 10).

It should be emphasized that the irradiation dose used for pre-fried bacon in these experiments is the 12D dose of ionizing radiation for raw bacon. This dose results in a sterile product, safe from C. botulinum growth and toxin formation. Since pre-frying results in a higher salt content and lower water activity in the product, the 12D irradiation sterilizing dose for pre-fried bacon will be much lower. It is estimated that 10 to 15 kGy of irradiation will be sufficient for pre-fried bacon. This has to be demonstrated.

B. Low dose irradiated (radurized) bacon

Bacon is distributed in the US mainly as slices that are vacuum packed in transparent plastic film, 1 lb packages, shipped, stored, and marketed under refrigeration. Refrigerated shelf-life of the product guaranteed by meat packers to grocery stores and to consumers is 45 to 60 days. Loss of vacuum packaging and bacterial growth limit the shelf-life, the detectable signs being discoloration of the packed bacon, followed by slime formation and off-odor. The nitrite addition at the level of 120 ppm in commercial bacon, together with the added salt, controls the bacterial growth and assures the needed shelf-life of 60 days. This high level of nitrite is needed also in commercial bacon to prevent growth and toxin formation by C. botulinum in case of mishandling of the product during distribution or by consumers (holding the product at temperatures over 10C). Irradiation of bacon for refrigerated distribution should be particularly welcomed by bacon processors since irradiation can be applied to the product packed in conventional packaging for which highly automated process have been developed at a high cost to industry. The dose of irradiation needed for bacon for refrigerated distribution would be much lower than the 12D sterilizing dose. For the irradiated product processed without nitrite or with only 20 ppm added nitrite, the irradiation dose should be sufficient to provide safety to the product comparable or better than presently is assured by the 120 ppm nitrite addition to commercial nonirradiated bacon. Such irradiation dose, by our estimation, will be in the range of 7.5 to 10 kGy at refrigerated temperature of 5 ± 5C.

Application of low dose irradiation to bacon packed in conventional packaging was investigated on the product cured without nitrite, with 20 and 40 ppm nitrite, as well as with 20 ppm nitrite and 20 ppm nitrate additions, along with other common curing components as listed in Table 7. The irradiation dose was 7.5 kGy. After irradiation, the product was stored in a refrigerator at 5C ± 1C up to 80 days. Nonirradiated samples were also stored for comparison. The most dramatic effect of the irradiation was observed in the color of the product, which was the normal pinkish-red color of raw wholesome bacon desired by the processor and the consumer.

The color and appearance of nitrite-free bacon were equally good up to 80 days storage at 5C, the longest period investigated. Nonirradiated bacon samples, cured without nitrite, showed objectionable discoloration after 2 weeks of storage. After 30 days storage, the product was slimy and gave off a definite putrid odor. Discoloration was less severe in nonirradiated bacon cured with 20 ppm and 40 ppm nitrite additions. The lb bacon samples, packed in the conventional bacon packaging representing five different cures, irradiated (7.5 kGy) and nonirradiated were analyzed for the total aerobic plate count (APC) after 78 days storage at 5 $\pm$ 1C. The results of this investigation are given in Table 13. As the data indicate, irradiation with 7.5 kGy is sufficient to destroy the common bacon spoilage microorganisms.

The irradiated bacon samples processed with the five cures listed in Table 13 were subjected to an informal evaluation by NARADCOM food technologists after 80 days storage at 5 $\pm$ 1C. All samples before frying, including the two samples without nitrite, were judged highly acceptable for color, odor, and overall appearance, and were similar to bacon cured with the high level of added nitrite (120 ppm). After frying, the bacon samples of cures I and II, without nitrite (Table 13) were different in color, odor, and flavor than the bacon samples cured with nitrite (lots III, IV and V, Table 13), but the product was judged acceptable as fried bacon. The bacon sample cured with 20 ppm nitrite addition (lot III, Table 13) was judged as normal bacon in all its quality characteristics applicable to commercial nonirradiated bacon cured with 120 ppm nitrite. It can be concluded that, as in irradiation-sterilized bacon, the added nitrite in low dose-irradiated bacon can be reduced to 20 ppm while preserving all the quality characteristics of the product before and after frying. Nitrite addition can also be entirely eliminated, giving a product with the desired color and appearance before frying, that, however, changes to a non-cured color after frying. The consumers will have to accept slight differences in the odor and flavor of the bacon cured without nitrite in case the nitrite ban becomes a reality.

C. Cost of irradiation

Irradiation technology already esists and is used widely by chemical and medical supply industries. Food irradiation on a commercial scale can be established, based on the experience of these industries.

The current supply of radioisotopes, a significant portion of which is cesium-137, is sufficient to satisfy all needs in food irradiation. At present these by-products from atomic reactors are stored underground and are being wasted. Their use for food irradiation would provide additional energy, resulting in energy savings of other available energy sources. The cost of irradiating bacon and the associated energy savings has been recently estimated by Brynjolfsson (1979). Irradiation sterilization of bacon at 25 kGy under refrigeration would cost about 0.8¢/lb; if irradiation sterilized while frozen, the cost of irradiating and freezing would be about 3¢/lb. Using substerilizing irradiation doses of 7.5 to 15 kGy would cost about 0.7C/lb. From an organoleptic standpoint, there is no need to irradiate bacon in a frozen state. However, there might be some concern about the greater effect of irradiation on the vitamin B_1 content and the lipids of irradiated bacon. This has yet to be determined.

Irradiation sterilization of ham, corned beef, frankfurters, and other meats has to be accomplished in the frozen state (-40 $\pm$ 5C) to preserve their sensory properties (mainly flavor). The cost of irradiation of these products with sterilizing doses of 25 to 50 kGy, including the freezing before and during irradiation, would be approximately twice as high as irradiation sterilizing bacon in the frozen state or about 6¢/lb.

Irradiation will be applied at the end of the processing, in fact, after the product is packed and boxed and on its way to a warehouse or to the distribution truck, as outlined for bacon in Table 14. The cost of irradiation as shown in Table 15 for the sterilization (25 kGy) of the bacon by four different sources, considering the 5-year straight-line depreciation of the initial capital outlay, normalized per pound of irradiated bacon for a plant size of 100,000,000 lb/year capacity (Brynjolfsson, 1979). The same facility, of course, can be used for irradiating other foods.

D. FDA and USDA clearances

Raw bacon, vacuum-packed in metal cans and sterilized by irradiation (56 kGy) was approved by the FDA and USDA in 1963. In 1968, clearance was rescinded, as additional data was thought necessary. At present, consultations are in progress among the Army, USDA, and FDA to evaluate irradiation as an alternative to nitrite and to review requirements for obtaining clearance for its use. According to Califano, Secretary of Health, Education and Welfare (New HEW News, 30 March 1979) "the use of nitrite as a preservative could be ended safely within 3 years - by 30 April 1982." This period of time is sufficient for getting the needed FDA and USDA clearance for irradiated bacon if the Army-FDA-USDA determine what further data are needed and start working on obtaining additional data before the end of this year.

The clearances for other irradiation sterilized meats will be included in the clearance of irradiation sterilized chicken, the wholesomeness studies of which involve multigeneration animal feeding tests and are now close to completion. Using the wholesomeness data for irradiation-sterilized chicken, supplemented with broad chemical and microbiological data on other meats (beef, pork, ham) and applying the principle of chemiclearances, it is expected that the irradiation will be cleared by the health authorities as the food process applicable to all foods. Consultations with the FDA on the subject are in progress.

SUMMARY

1. Nitrite in commercial cured meats is used currently at the level of 120 ppm in bacon and 156 ppm in other meats.

2. These high nitrite levels are used primarily to control *C. botulinum* and, thus, to protect customers from an incidence of botulinum food poisoning. Other effects of the nitrite use are development of the characteristic color and flavor of the products.

3. Irradiation very effectively destroys *C. botulinum.* This allows a great reduction in the addition of nitrite to cured meats preserved by irradiation.

4. Addition of nitrite to irradiated cured meat products can be limited to the low levels needed only for the color, odor, and flavor of the products. Thesy are: (a) 20 ppm in bacon; (b) 25 ppm each, nitrite and nitrate, in ham; (c) 50 ppm in corned beef and frankfurters.

5. In some products perserved by irradiation, such as bacon, corned beef and frankfurters, the use of nitrite can be entirely eliminated. The

resulting nitrite-free products are of acceptable quality and retain their product identity even though slightly different in color and flavor from what consumers are used to in nitrite-cured products.

6. Application of irradiation to bacon, cured without nitrite or cured with only 20 ppm added nitrite, is particularly successful; it provides safety from botulism, destroys residual nitrite, and results in a product which, after frying, is either completely free from nitrosamines or only has the nitrosopyrrolidine content at the threshold of detectability (1 ppb).

7. Production techniques and irradiation technology are well developed and they can be economically applied to industrial processing.

8. The main obstacle to the use of irradiation industrially is the absence of the needed FDA and USDA clearances for its application to foods. At present, consultations are in progress among the Army, FDA and USDA to evaluate the feasibility of irradiation as an alternative to nitrite in bacon and to determine the requirements for obtaining the needed clearance for its use.

9. With concentrated effort by all concerned and with increased fund allocations by the Congress, the use of irradiation to replace nitrite as a preservative can become a reality within 3 years (and in some foods, such as bacon, even sooner), the time span needed for a safe ban of nitrite in cured meats and other foods, as estimated recently by the Secretary of HEW.

Table 1. Minimal Irradiation Sterilizing (12D) Dose in kGy
(1 Gy = 100 Rad)

Food	Radiation Temperature (C°)	Method of Estimating 12D Dose[a]	
		Extreme Value[b]	Spearman-Karber[c]
Beef	-30 ± 10	41.2	43.4
Chicken	-30 ± 10	42.7	44.3
Ham	-30 ± 10	31.4	38.1
Pork	-30 ± 10	43.7	39.2
Codfish Cake	-30 ± 10	31.7	32.4
Corned Beef	-30 ± 10	26.9	24.4
Pork Sausage	-30 ± 10	25.5	26.5
Bacon	5 to 25	--	25.2

a. based on recoverable botulinal cells and an assumed one most resistant strain/can.

b. based on an assumed exponential spore death rate with an initial shoulder.

c. based on an assumed exponential spore death rate without an initial shoulder.

Source: Dr. D. B. Rowley, NARADCOM

Table 2. Minimal additions of nitrite to irradiated meats

Product	Minimum Addition ppm $NaNO_2$	Product Quality
Bacon	None	Slightly different color and flavor.
	20	Color, flavor and taste like in normal commercial bacon.
Ham	25	Color fading.
	25/25 1/	Color stabilized.
	None	In research state (texture excellent)
Corned Beef	50 2/	Regular quility product.
	None	No color, otherwise acceptable.
Frankfurters	50	Good quality product.
	None	Acceptable, different flavor and color.

1/ 25 ppm $NaNO_3$ addition is needed to prevent fading of the color.

2/ 25 ppm $NaNO_2$ addition is sufficient if $NaNO_2$ is uniformly distributed during pumping.

Table 3. Brine Composition and Addition to Ham

Cure[a]		Added to Ham[b]
Composition	%	
NaCl	16.0	2.4%
Na-TPP	2.0	0.3%
Na-Asc.	0.183	275 ppm
Na-Eryth	0.183	275 ppm
$NaNO_2$	0.0166	25 ppm
$NaNO_3$	0.0166	25 ppm
Water	81.6	--

a. For 15% cure addition

b. Based on 100% yield-to-green

Table 4. Ham, Color Evaluation (n = 16) Served Hot

Added NO_2/NO_3 ppm	Nonirradiation 0	Nonirradiation 2 (hrs)	32 kGy at -40^{o}C 0	32 kGy at -40^{o}C 2 (hrs)
25/0	7.8	6.4	6.9[a,b]	4.6[a]
50/0	7.5	6.4	6.3[a]	4.6[a]
75/0	7.6	6.4	7.1[a,b]	5.2[a,b]
25/25	7.6	6.6	7.8[b]	6.3[b,c]
25/50	7.4	6.4	7.8[b]	6.5[c]
Significant Difference	NSD	NSD	SD	SD

No significant difference between means with the same letter.

Table 5. Ham - Consumer Preference (n = 35)

Lot	NO_2/NO_3 ppm	Served Cold	Served Hot
78/24	25/0	5.7 ± 2.1	5.4 ± 2.1
78/24	50/0	5.3 ± 2.0	5.7 ± 1.9
78/24	25/25	5.7 ± 2.0	7.4 ± 1.7
78/16	25/50	5.6 ± 1.6	5.8 ± 2.0
78/16	75/0	6.1 ± 2.0	5.7 ± 2.0
Significant Difference		NSD	NSD

32 kGy at -40C ± 5C.

Table 6. Consumer Panel Evaluation of Irradiated[a] Corned Beef

Sample		Preference Rating[b]	
ppm $NaNO_3$	ppm $NaNO_2$	Mean	Standard Deviation
600	150	6.19[c]	$\pm$ 1.96
100	25	6.03[cd]	$\pm$ 1.66
0	150	5.47[d]	$\pm$ 1.88
0	25	6.37[c]	$\pm$ 1.34

a. 25 - 33 kGy at -30C $\pm$ 10C.

b. 32 panelists, 30 days storage.

Ratings followed by the same letter are not significant ($P < 0.05$)

Table 7. Bacon - Expt. 4
Added Levels of Curing Components*

Lot	NaCl %	Sucrose %	Na-TPP %	$NaNO_2$ ppm	$NaNO_3$ ppm	Asc./Eryth. ppm
I	1.5	0.75	0.3	0	0	275
II	1.5	0.75	0.3	0	0	550
III	1.5	0.75	0.3	20	0	550
IV	1.5	0.75	0.3	40	0	550
V	1.5	0.75	0.3	20	20	550

*based on 12.5% pump, 11% pickle retention and 100% yield-to-green after smokehouse processing.

Table 8: Bacon: Sensory Quality
30 kGy at -30C

Added, ppm			Sensory Quality			
$NaNO_2$	$NaNo_3$	Na-Eryth	Color	Odor	Flavor	Texture
0	0	275	5.7±0.8	6.9±1.0	6.5±1.1	6.3±1.1
0	0	550	6.2±1.5	6.8±1.2	6.3±2.3	6.5±1.7
20	0	550	6.7±1.1	6.9±1.0	6.0±2.0	6.8±1.1
40	0	550	7.2±1.0	6.9±1.0	6.6±1.4	6.7±1.3
20	20	550	6.5±1.4	6.9±0.9	6.4±1.9	6.3±1.6
$P < 0.05$			NSD	NSD	NSD	NSD

Table 9: Bacon: Preference by Consumer Panel
(Randomized Block, 5 of 5, 35 subjects)

Added, ppm			Nonirrad.	30 kGy at -30C
$NaNO_2$	$NaNO_3$	Na-Eryth		
0	0	275	5.00 ± 2.11	5.91 ± 1.72
0	0	550	6.31 ± 1.39	5.26 ± 1.75
20	0	550	6.37 ± 1.78	5.86 ± 1.85
40	0	550	6.80 ± 1.69	6.31 ± 1.66
20	20	550	6.43 ± 1.94	5.46 ± 2.15
Duncan	<0.5	LSD	0.80	0.65

Table 10: Nitrosamines in Irradiated Bacon
(30 kGy at -30C)

Added, ppm:			Pre-Fried			Regular Bacon*		
$NaNO_2$	$NaNO_3$	Ac/Er	Res. $NaNO_2$	NDMA ppb	NPYR ppb	Res $NaNO_2$	NDMA ppb	NPYR ppb
0	0	275	N.D.1/	n.d.2/	n.d.2/	N.D.1/	n.d.2/	n.d.2/
0	0	550	N.D.	n.d.	n.d.	N.D.	n.d.	n.d.
20	0	550	N.D.	n.d.	1	N.D.	n.d.	n.d.
40	0	550	N.D.	n.d.	2	N.D.	n.d.	1
20	20	550	N.D.	n.d.	1	N.D.	n.d.	1

* Edible portion after frying

N.D.1/ = None detected, min. detectability, -0.5 ppm $NaNO_2$

n.d.2/ = None detected, min. detectability, <1 ppb NA

Table 11. Pre-Fried Bacon - Expt. 4
Irradiated: 30 kGy at -30C
Technological Panel (n = 10)

Added, ppm:			Sensory Quality			
$NaNO_2$	$NaNO_3$	Asc.	Color	Odor	Flavor	Texture
0	0	275	5.8[a]	6.7	6.5	6.6
0	0	550	6.0[a]	7.2	6.1	6.4
20	0	550	7.1[b]	7.0	6.7	6.6
40	0	550	7.2[b]	6.7	6.6	6.7
20	20	550	7.6[b]	6.8	6.7	6.7
Significant Difference			SD	NSD	NSD	NSD

a,b = Means with the same letters are not significantly different

Table 12. Prefried Bacon - Expt. 4
Consumer Panel for Preference (n = 35)

Added, ppm:			Preference Scores:	
$NaNO_2$	$NaNO_3$	Asc.	Nonirradiated	30 kGy at -30C
0	0	275	5.1 ± 2.2^{a}	5.9 ± 1.6
0	0	550	$5.5 \pm 2.2^{a,b}$	5.9 ± 1.6
20	0	550	$6.2 \pm 2.0^{b,c}$	6.0 ± 1.6
40	0	550	6.3 ± 1.9^{c}	5.7 ± 1.8
20	20	550	6.7 ± 1.8^{c}	6.2 ± 1.6
Significant Difference			SD	NSD

a, b, c = Means with the same letters are not significantly different ($p<0.05$)

Table 13. Bacon: Aerobic Plate Count (APC)
78 Days at 5C ± 1C

Added during curing, ppm:			APC, cells/gram			
			Nonirradiated		7.5 kGy	
$NaNO_2$	$NaNO_3$	Na-Eryth.	Lean	Fat	Lean	Fat
0	0	275	>$3X10^6$	>$3X10^6$	10*	10
0	0	550	>$3X10^6$	$3X10^7$		
20	0	550	$7.8X10^6$	$7.4X10^6$		
40	0	550	$2.6X10^6$	$1.1X10^7$		
20	20	550	>$3X10^6$	>$3X10^6$		

*10 = Negative at 1:10 dilution.

Table 14. Bacon
Irradiation as an Alternative to Nitrite
Overall Processing

Curing ⟶ Smoking ⟶ Chilling ⟶ Pressing ⟶

Slicing ⟶ Vacuum Packaging ⟶ Boxing —(x)⟶

Storage —(x)⟶ Shipping ⟶ Distribution.

(x). Irradiation applied at wither one of these points.

Table 15. Cost of Irradiation Sterilizing Bacon
Dose: 2.5 Mrad at Refrigerated Temp.
Plant size: 1 million lbs./year

Source	5-year Plant Depreciation ¢/lb	Operation ¢/lb	Total ¢/lb
Co-60 isotope	2.03	1.20	3.22
Cs-137 isotope	0.03	0.35	2.38
10 MeV accelerator	0.49	0.43	0.92
4 MeV accelerator	0.36	0.40	0.76

Source: A. Brynjolfsson, NARADCOM, 1979

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